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PROCEEDINGS OF A WORKSHOP OF CLIMATE CHANGE AND WATER RESOURCES

COMPTES RENDUS DE L'ATELIER SUR LES CHANGEMENTS CLIMATIQUES ET LES RESSOURCES HYDRIQUES

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PROCEEDINGS
OF A
WORKSHOP OF CLIMATE CHANGE
AND WATER RESOURCES

National Hydrology Research Centre

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COMPTES RENDUS
DE
L'ATELIER SUR LES CHANGEMENTS CLIMATIQUES
ET LES RESSOURCES HYDRIQUES

Centre national de recherche en hydrologie

Saskatoon (Saskatchewan), 17 et 18 mai 1989

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EXECUTIVE SUMMARY

In May 1989 more than 40 physical and social scientists participated in a two-day workshop in Saskatoon dealing with climate change and water resources. The workshop was jointly sponsored by the Canadian Climate Centre and the Inland Waters Directorate and took place at the National Hydrology Research Centre. It was held as a response to a decision of the Climate Program Board at its January 1988 meeting. To satisfy the needs of the Climate Program Board and of the climate research community, the following workshop objectives were established:

1) Facilitate the exchange of information and views regarding Canadian studies of the impacts of climatic variability and change on water resources.

2) Formulate some practical recommendations regarding research and technology transfer initiatives for the Climate Program Board.

The workshop began with a number of presentations by national experts on different aspects of the climate change issue. After these presentations, workshop attendees were divided into four working groups. Two of these groups dealt with questions related to the physical impacts of climatic change while the other two groups dealt with socio-economic issues. The working groups responded to questions that were posed by the workshop organizers and developed recommendations and issue statements, which were then presented and discussed in a plenary session. The reports from the individual working groups along with the issues raised in the formal presentations have been synthesized into the list of recommendations which follows this summary.

The presentations covered four areas of concern; namely, the global climate models, information needs for water resources management, methodologies for assessing the hydrological impacts of climatic variability and change and the socio-economic impacts of climatic change on water resources. It was recognized that a gap exists between the public's expectations of our ability to provide definitive information on the future impacts of climatic change and the ability of science to provide final answers at this time. The discussions indicated that global climate models were not yet sufficiently developed to make statements about the impacts of climate at a local scale although they could provide guidance at larger scales for temperature and, with lesser confidence, precipitation. The development of more reliable model scenarios awaits the incorporation of better parameterizations of clouds and land surface processes into these global climate models.

Speakers identified a number of needs for better information on climatic change to deal with water resource planning and management. Specific needs included a better knowledge of extremes and variability to provide better guidance on possible changes in design criteria for water distribution and control systems. It was noted that prairie water supply systems currently operate at the margin and a small change in either the supply or the demand could put some of the present systems at risk. Other climatic changes that are expected to influence water management include rain/snow ratios in the Great Lakes area and the influence of increasing temperature and evaporation on consumptive demand.

The methodologies for assessing hydrological impacts were also addressed. A number of research needs were identified including the need to gain a better understanding of the role of vegetation and other land-based processes in the hydrological cycle and to develop an ability to incorporate this understanding into hydrological models. The lack of knowledge of the spatial variability of hydrometeorological and hydrological parameters such as evaporation, precipitation and soil moisture was also identified. It was noted that the problems related to assessing the results of current climatic variability on hydrology were not fully understood and that new models were needed to address these problems.

A range of issues was identified in the socio-economic session. The need for socio-economic sectoral studies and integrated regional or provincial studies was identified. Integrated studies are needed because climatic change impacts all sectors and these sectoral impacts reinforce each other, possibly in producing an even greater economic impact. Socio-economic models do exist in the water sector. While these models are of use in water management, they are limited by their ability to incorporate all the adaptations which people would make to their lifestyles under a changed climate. A closer interaction between physical and social scientists is needed to successfully undertake such studies.

The working groups dealt with both physical and socio-economic issues. The groups dealing with physical impacts felt that there was a definite lack of good models for climate change impacts work. Given the current status of Global Climate, or General Circulation, Models (GCMs), there was general agreement that no GCM should be preferred above another. Research is needed to develop these models so they become more realistic. The development of models is currently constrained by the lack of computing power and experts to develop GCMs. The need for higher resolution outputs in shorter time frames was seen as a priority requirement by users of the scenarios. Specific research needs were felt to include the production of more realistic precipitation scenarios and the inclusion in the models of better parameterizations of oceans, forest cover, lakes, mountains and other physiographic features. Similar needs were recognized for water balance models that may be used for studying the impacts of climate change on water resources. The absence of good measurements for use in verifying water balance models was seen as a major weakness in current research initiatives.

One source of scenarios is paleoclimatological data. It was felt that our knowledge of past extremes and long-term averages is incomplete and hence our knowledge of the total range of potential climate scenarios is inadequate.

The issue of the measurement of current hydrological regimes was raised in several contexts. It was recognized that we are unable to characterize evapotranspiration, groundwater and soil moisture regimes over an area, even though we have a good understanding of the individual hydrological processes involved. More comprehensive, long-term observing programs are needed to document both the spatial and temporal variations in these parameters and to understand how these processes interact.

Workshop participants felt that models at all scales were necessary to study the impacts of climate change on water resources. For example, small scale models are needed for impact studies, while medium and large-scale models are required for process analysis.

The need to study how society now responds/adapts to changes in the water cycle and how water is currently managed must be analyzed and assessed. Research is needed on the flexibility of water resource systems, using vulnerability indicators, and on the rationale used for the allocation of water. The socio-economic working groups felt that there was a requirement for case studies to determine how factors such as decision-making infrastructures and social expectations influence the flexibility and elasticity of water basin management. Problem-solving at the design stage and early public involvement in the decision process are two further issues that must be addressed.

In reviewing the need for better information on socio-economic impacts, three factors were recognized as important in setting priorities for socio-economic impact studies. These included

1) the relative significance of the relationship between water supply and economy for specific regions and activities;
2) the public values placed on water resources and changes in these values;
3) the need to know the requirements for information inputs in policy formulation and the level of research that is appropriate to carry out at the present time.

The limitations and strengths of the socio-economic effort in climate change studies were reviewed. It was suggested that the major limitation facing social scientists was the need to fit socio-economic research and policy analysis into a biophysical "agenda" and mode of intellectual discourse. In response, researchers must clearly identify the points of contact between the two areas of discipline. The social science emphasis should be on the adaptation of people in a constantly changing society. The concepts of social and biophysical resilience and an integrative research approach are important considerations. Historical examples of societal adaptation to climatic variability should be used as analogues in socio-economic impact studies of future climatic change.

The distinction between the social (behavioral) and economic responses was recognized. The need to develop response strategies that could slow the increasing concentrations of CO_2 in the atmosphere was recognized as one priority area of research.

Public education is seen as an important issue by all working groups. The public must have realistic expectations of the results of current impact studies and how they bear on decision-making. A number of the groups felt that the Canadian Climate Program should increase its efforts in educating the public on the importance, uncertainties and choices involved in dealing with the climatic change issue.

Recommendations

A. Global Climate Models and Scenarios

1) Physical studies and modelling work should be undertaken to develop better areal representations for evapotranspiration/evaporation processes, soil moisture, mixed surface types and other land surface processes for use in the Global Climate Models. In addition, field studies are needed to gain a better understanding of these hydrological and hydrometeorological processes.

2) Regionalized climate models, capable of producing precipitation and evaporation fields, should be developed at appropriate scales for hydrologic models and general water research applications (higher resolution and limited area models).

3) The feasibility of developing short-term (1-to 5-year) scenarios showing the range of climatic variability and changes should be assessed.

4) A review of the effects of climate variability and change on the water requirements for ecological processes and on ground-water systems should be undertaken.

5) Climate diagnostic studies are needed to gain a better understanding of the causes and nature of the variability of precipitation at all scales.

B. Physical Impacts

1) A study of the possible effects of climate variability and change on water supply and reliability on appropriate hydrologic design statistics reliability is needed.

2) The roles, advantages and disadvantages of deterministic hydrological models versus probabilistic models should be assessed in light of requirements of climate/hydrology studies.

3) Further development and refinement of water balance/watershed models for better assessment of hydrologic/water resource impacts of climatic change is needed.

4) Impact studies integrating the effects of climate variability and change on water, agricultural lands, wetlands and forests should be undertaken for large eco-regions (the Prairies, coastal regions, Great Lakes basin, the North).

C. Socio-economic Impacts

1) A study should be undertaken to assess and rate the vulnerability of natural and controlled water systems to possible climatic changes and to identify policies that increase the resilience of these water resources.

2) A methodology similar to risk management should be developed to incorporate the uncertainty of climate scenarios and impact assessment models, the influence and availability of appropriate information for decision-making and the institutional processes of decision-making into a public mechanism for responding to climatic change.

3) Historic human and societal responses to the effects of climatic variability should be reviewed to develop analogue models that could be used in formulating strategies and policies for responding to future climatic change.

4) An assessment should be made of the market and extra-market values of various water uses (individuals and industries).

5) Pilot studies integrating biophysical, social and economic impacts of climatic variability and change and the influence of changing policies associated with adaptation to climatic change should be undertaken for the North, the Great Lakes, the Prairies and coastal regions.

D. Policy Analysis

1) Current impact research should be reviewed to determine how well this meets the near-future (5-yr) water policy needs.

2) An assessment of the effects and constraints of inter-jurisdictional responsibilities and decision-making processes on Canada's ability to respond to the anticipated effects of climatic change on the water sector should be carried out.

3) Mechanisms for incorporating long-term issues such as climatic variability and change and sustainable development into ongoing water management decisions and policy development should be developed.

E. Administrative Issues

1) The Canadian Climate Program Board should take concrete steps to improve public awareness of the issue of climatic change and its potential impacts, and to increase private sector participation in studying and responding to the issue.

2) The process of developing and funding research initiatives in impact assessment should be reviewed by a small task force with a substantial representation from the Socio-Economic Impacts Committee of the Climate Program Board and the socio-economic and physical sciences research communities.

3) The Climate Program Board should set aside an appropriate amount of money and issue a call for proposals that are interdisciplinary (and inter-jurisdictional where appropriate) and involve government, industry, university and non-government organizations in studying climatic change impacts and response options.

4) The Climate Program office should facilitate the development of a network of those conducting impacts and model development research and serve as an information centre for work and activities related to synthesis, analysis and dissemination.

5) Workshops on climatic change should be organized on a systematic and regular basis and aimed at bringing together biophysical and social scientists to discuss the climate change issue and review research methodologies.

6) Educational material should be developed to encourage water conservation, reduction in CO_2 emissions, increased forestation, pollution reduction and renewable energy sources.

SOMMAIRE

En mai 1989, plus de 40 spécialistes en sciences physiques et sociales se sont réunis à l'Institut national de recherche en hydrologie, à Saskatoon, dans le cadre d'un atelier de deux jours sur les changements climatiques et les ressources hydriques. Cet atelier, qui était parrainé conjointement par le Centre climatologique canadien et la Direction générale des eaux intérieures, faisait suite à une décision prise par le Conseil chargé du Programme de climatologie lors de sa réunion en janvier 1988. Les objectifs de cet atelier, qui ont été établis en réponse aux besoins définis par le Conseil chargé du Programme de climatologie et la collectivité scientifique de climatologie, se définissaient comme suit :

1) faciliter les échanges d'informations et d'opinions sur les études canadiennes traitant des répercussions de la variabilité et des changements du climat sur les ressources en eau, et

2) formuler des recommandations pratiques en matière de recherche et de transfert de la technologie, à l'intention du Conseil chargé du Programme de climatologie.

L'atelier a débuté par une série d'exposés présentés par des spécialistes nationaux et portant sur différents aspects des changements climatiques. Après la présentation de ces exposés, les participants ont été répartis en quatre groupes de travail. Deux de ces groupes ont été chargés d'étudier les questions liées aux répercussions physiques des changements climatiques, alors que les deux autres devaient se pencher sur les aspects socio-économiques. Les groupes de travail ont examiné les questions qui avaient été soulevées par les organisateurs de l'atelier et ils ont formulé des recommandations et des énoncés de principe qui ont ensuite été présentés à l'ensemble des participants au cours d'une discussion en séance plénière. Les rapports des différents groupes de travail, de même que les questions soulevées lors des exposés officiels, ont été résumés en une liste de recommandations qui suit le présent sommaire.

Les exposés ont porté essentiellement sur quatre aspects, à savoir les modèles climatologiques mondiaux, les données requises pour la gestion des ressources hydriques, les méthodes utilisées pour évaluer les impacts hydrologiques des changements et de la variabilité du climat et enfin les répercussions socio-économiques des changements climatiques sur les ressources en eau. Les participants ont souligné l'écart qui existe entre d'une part les attentes du public quant à notre capacité de fournir des renseignements précis sur les impacts futurs des changements climatiques et, d'autre part, la capacité des scientifiques de fournir des réponses définitives à ce stade-ci. Les discussions ont également fait ressortir le caractère inadéquat des modèles climatologiques mondiaux actuels pour évaluer les impacts du climat à l'échelle locale; ces modèles peuvent toutefois être utilisés à plus grande échelle pour la température et aussi, quoique à un niveau de confiance moins élevé, pour les précipitations. Un meilleur paramétrage des processus qui se déroulent dans les nuages et à la surface du sol ainsi que l'intégration de ces données aux modèles climatologiques mondiaux sont nécessaires à la mise au point de modèles plus fiables.

Les conférenciers ont précisé, dans une certaine mesure, les données sur les changements climatiques requises pour la planification et la gestion des ressources en eau. Parmi ces besoins, mentionnons l'approfondissement des connaissances sur les conditions climatiques extrêmes et sur la variabilité des conditions afin d'obtenir une meilleure indication des changements pouvant être apportés aux normes de conception des systèmes de distribution et de régulation de l'eau. À l'heure actuelle, les systèmes d'approvisionnement en eau dans les Prairies fonctionnent à la limite et une fluctuation même faible de l'offre ou de la demande pourrait mettre en péril certains d'entre eux. Parmi les autres changements climatiques susceptibles d'influer sur la gestion des ressources hydriques, citons le rapport pluie/neige dans la région des Grands Lacs et l'effet de l'élévation de la température et de l'évaporation sur la demande à la consommation.

Les participants ont également discuté des méthodes utilisées pour évaluer les impacts hydrologiques et ils ont indiqué un certain nombre de domaines qui devraient faire l'objet de recherches plus poussées. Mentionnons entre autres la nécessité de mieux comprendre le rôle de la végétation et des autres phénomènes terrestres dans le cycle hydrologique et d'acquérir les compétences nécessaires pour intégrer ces nouvelles connaissances aux modèles hydrologiques. Ils ont de plus souligné le manque d'information sur la variabilité spatiale des paramètres hydrométéorologiques et hydrologiques comme l'évaporation, les précipitations et l'humidité du sol. Ils ont enfin précisé que les problèmes liés à l'évaluation des effets de la variabilité actuelle du climat sur l'hydrologie étaient mal compris et qu'il fallait de nouveaux modèles pour étudier ces problèmes.

Un certain nombre de questions ont été soulevées durant les séances portant sur les questions socio-économiques. Les participants ont souligné la nécessité de mener des études socio-économiques sectorielles, ainsi que des études régionales ou provinciales intégrées. Des études intégrées s'imposent, car les changements climatiques ont des répercussions sur tous les secteurs et que ces impacts s'ajoutent l'un à l'autre pour produire potentiellement un impact économique encore plus grand. Certes, il existe des modèles socio-économiques qui s'appliquent au secteur de l'eau. Cependant, même si ces modèles peuvent être utilisés pour la gestion de l'eau, ils sont limités par leur incapacité d'intégrer tous les changements que les gens devraient apporter à leur mode de vie advenant la modification du climat. Un lien étroit doit s'établir entre les spécialistes des sciences sociales et physiques pour assurer le succès des études requises.

Les groupes de travail ont étudié à la fois les aspects physiques et socio-économiques. De l'avis des groupes chargés d'étudier les impacts physiques, il y a un manque évident de modèles adéquats pour étudier les répercussions des changements climatiques. Par ailleurs, étant donné l'état actuel des différents modèles climatologiques mondiaux ou modèles de circulation générale (GCM), les participants ont convenu qu'aucun modèle n'était préférable à un autre. Les recherches doivent se poursuivre afin de mettre au point des modèles plus réalistes. Cependant, la mise au point de ces modèles est actuellement limitée par le manque de spécialistes et de puissance de calcul. Les utilisateurs des scénarios jugent par ailleurs prioritaire la mise au point de modèles à plus haute résolution dans un laps de temps plus court. Certains besoins précis ont été identifiés, notamment la production de scénarios plus réalistes concernant les

précipitations et l'intégration, dans les modèles, d'un meilleur paramétrage des océans, du couvert forestier, des lacs, des montagnes et autres éléments physiographiques. Des besoins similaires ont été identifiés en rapport aux modèles sur le bilan hydrique, lesquels pourraient être utilisés pour étudier les répercussions des changements climatiques sur les ressources en eau. L'absence de bonnes mesures pour vérifier les modèles sur le bilan hydrique a été citée comme une des principales lacunes des projets de recherche actuels.

L'établissement des scénarios se fait notamment à partir des données paléoclimatologiques. Or les participants estiment que nos connaissances sur les conditions climatiques extrêmes antérieures et sur les moyennes à long terme sont incomplètes et, par conséquent, que nous connaissons mal l'éventail complet de scénarios climatologiques potentiels.

La question de la mesure des régimes hydrologiques actuels a été soulevée à plusieurs reprises. De l'avis des participants, nous sommes incapables de caractériser l'évapotranspiration, les régimes hydrogéologiques et les régimes d'humidité du sol dans une région donnée, même si nous comprenons bien chacun des procédés hydrologiques individuels en cause. Il faut entreprendre des programmes d'observation plus complets et à plus long terme pour recueillir des données sur les variations spatiales et temporelles de ces paramètres et comprendre l'interaction des différents phénomènes.

Les participants ont indiqué par ailleurs qu'il fallait mettre au point des modèles à toutes les échelles pour étudier les répercussions des changements climatiques sur les ressources hydriques. Il nous faut ainsi des modèles à petite échelle pour les études d'impacts et des modèles à moyenne et à grande échelles pour l'analyse des processus en cause.

Il faut également étudier et analyser de quelle façon notre société réagit et s'adapte actuellement à la modification du cycle de l'eau et comment les ressources en eau sont gérées à l'heure actuelle. De plus, des recherches doivent être entreprises sur la flexibilité des systèmes hydrologiques, en utilisant des indicateurs de vulnérabilité, ainsi que sur les critères déterminant le mode d'affectation des ressources en eau. Les groupes de travail chargés des questions socio-économiques estiment qu'il y a lieu de mener des études de cas pour déterminer dans quelle mesure certains facteurs, comme les infrastructures de prise de décision et les attentes sociales, influent sur la flexibilité et l'élasticité de la gestion des bassins hydrologiques. La résolution des problèmes durant la phase de conception, ainsi que la participation du public dès les premières phases du processus de prise de décisions, sont deux autres aspects qui devront être étudiés plus à fond.

La détermination des besoins en matière d'information sur les répercussions socio-économiques a fait ressortir trois facteurs jugés importants dans l'établissement des priorités des études sur les impacts socio-économiques; il s'agit :

1) de l'importance relative du rapport entre l'approvisionnement en eau et l'économie dans des régions et des secteurs d'activités particuliers;
2) de la valeur que le public accorde aux ressources en eau et de la fluctuation de cette valeur;

3) de la nécessité de préciser l'information requise pour l'élaboration des politiques et de déterminer le niveau de recherche jugé approprié à l'heure actuelle.

Les participants ont en outre passé en revue les lacunes et les points forts des volets socio-économiques des études sur les changements climatiques. Certains ont laissé entendre que la principale difficulté à laquelle étaient confrontés les spécialistes des sciences sociales aujourd'hui venait de la nécessité d'intégrer les recherches socio-économiques et les analyses de politiques à un «programme» biophysique et un mode de discours intellectuel. À cet égard, les chercheurs doivent définir clairement les éléments communs des deux disciplines. Les spécialistes des sciences sociales doivent mettre l'accent sur la façon dont les gens s'adaptent à une société en évolution constante. Les concepts de l'élasticité sociale et biophysique ainsi qu'une approche intégrée de recherche constituent d'autres aspects importants. Les exemples historiques sur l'adaptation des sociétés aux variations climatiques devraient servir de modèles aux études sur les impacts socio-économiques des changements climatiques futurs.

De l'avis des participants, il faut faire une distinction entre les adaptations sociales (comportement) et économiques. Par ailleurs, l'élaboration de stratégies visant à ralentir l'augmentation de la concentration en CO_2 dans l'atmosphère constitue, selon les participants, un des domaines prioritaires de recherche.

Enfin, tous les groupes de travail ont souligné l'importance de l'éducation du public. Le public doit avoir des attentes réalistes quant aux résultats des études d'impact actuelles et à leurs effets sur le processus de prise de décisions. Un certain nombre de groupes estiment en outre qu'il faudrait, dans le cadre du Programme canadien de climatologie, intensifier les efforts visant à informer le public sur l'importance des changements climatiques et sur les incertitudes et les choix qui y sont associés.

Recommandations

A. Modèles et scénarios climatologiques mondiaux

1) Entreprendre des études physiques et des travaux de modélisation pour mettre au point de meilleurs modèles géographiques sur les processus d'évapotranspiration et d'évaporation, l'humidité du sol, les types de surface mixtes et autres phénomènes qui se produisent en surface et les utiliser dans les modèles climatologiques mondiaux. Il faut en outre effectuer des études sur le terrain pour mieux comprendre ces processus hydrologiques et hydrométéorologiques.

2) Mettre au point des modèles climatologiques régionalisés aux échelles appropriées, capables de définir les champs de précipitations et d'évaporation et pouvant être appliqués aux modèles hydrologiques et aux recherches générales sur l'eau (modèles à plus grande résolution et à région limitée).

3) Évaluer la faisabilité d'élaborer des scénarios à court terme (1 à 5 ans) illustrant l'éventail des changements et de la variabilité du climat.

4) Étudier les effets de la variabilité et des changements du climat sur les besoins en eau pour les processus écologiques et sur les systèmes hydrogéologiques.

5) Entreprendre des études de diagnostic sur le climat pour mieux comprendre les causes et la nature de la variabilité des précipitations, à toutes les échelles.

B. Impacts physiques

1) Étudier les effets possibles de la variabilité et des changements du climat sur l'approvisionnement en eau et la fiabilité des statistiques pertinentes en matière de conception hydrologique.

2) Comparer les rôles, les avantages et les inconvénients des modèles hydrologiques déterministes à ceux des modèles probabilistes, en regard des besoins des études sur le climat ou l'hydrologie.

3) Améliorer et perfectionner les modèles sur le bilan hydrique et les bassins hydrographiques, afin de mieux évaluer les répercussions des changements climatiques sur les ressources hydrologiques et hydriques.

4) Mener des études d'impacts tenant compte des effets de la variabilité et des changements du climat sur l'eau, les terres agricoles, les terres humides et les forêts dans de grandes écorégions (Prairies, régions côtières, bassin des Grands Lacs, le Nord).

C. Répercussions socio-économiques

1) Mener une étude pour évaluer la vulnérabilité des régimes hydriques naturels et artificiels aux changements climatiques potentiels et pour déterminer les politiques susceptibles d'accroître l'élasticité de ces ressources en eau.

2) Mettre au point une méthode similaire à celle utilisée pour la gestion des risques, pour permettre l'intégration des incertitudes associées aux scénarios climatologiques et aux modèles utilisés pour les études d'impacts, des effets et de la disponibilité de données pertinentes pour la prise de décisions ainsi que des processus de prises de décisions à un mécanisme public d'adaptation aux changements climatiques.

3) Revoir les données historiques sur les réactions de l'homme et des sociétés aux effets des changements climatiques, afin de mettre au point des modèles analogues qui pourraient servir à l'élaboration des stratégies et des politiques d'adaptation aux changements climatiques futurs.

4) Déterminer les valeurs marchande et autres des diverses utilisations de l'eau (tant personnelles qu'industrielles).

5) Mener des études pilotes qui tiennent compte des répercussions biophysiques, sociales et économiques des changements et de la variabilité du climat ainsi que des effets de la modification des politiques résultant de l'adaptation aux changements climatiques, pour les régions du Nord, des Grands Lacs, des Prairies et du littoral.

D. Analyse des politiques

1) Passer en revue les études d'impacts actuelles pour déterminer dans quelle mesure celles-ci satisfont aux besoins à court terme (5 ans) de la politique relative aux eaux.

2) Déterminer dans quelle mesure les effets et les contraintes résultant du partage des responsabilités entre diverses autorités et du processus de prise de décisions influent sur la capacité du Canada de réagir aux effets prévus des changements climatiques sur le secteur de l'eau.

3) Mettre au point des mécanismes permettant d'intégrer certains facteurs à long terme, comme la variabilité et les changements du climat et le développement durable, aux processus permanents d'élaboration des politiques et de prises de décisions en matière de gestion des eaux.

E. Questions administratives

1) Le Conseil chargé du Programme canadien de climatologie devrait prendre des mesures concrètes pour mieux sensibiliser le public aux

changements climatiques et à leurs effets potentiels et pour accroître la participation du secteur privé aux études et aux interventions dans ce domaine.

2) Mettre sur pied un petit groupe de travail, constitué principalement de représentants du Comité des impacts socio-économiques du Conseil chargé du Programme de climatologie et des collectivités scientifiques (socio-économie et sciences physiques), pour revoir les processus d'élaboration et de financement des recherches sur les études d'impacts.

3) Le Conseil chargé du Programme de climatologie devrait réserver une somme d'argent appropriée pour le financement de projets de nature interdisciplinaire (et faisant appel au besoin à diverses autorités), auxquels participeraient les gouvernements, l'industrie, les universités et les organismes non gouvernementaux, pour étudier les répercussions des changements climatiques et les stratégies d'adaptation appropriées.

4) Le bureau du Programme canadien de climatologie devrait faciliter la mise sur pied d'un réseau des scientifiques qui poursuivent des études d'impact et des travaux de modélisation et servir de centre d'information sur les travaux et les activités liés à la synthèse, à l'analyse et à la diffusion des données.

5) Organiser, sur une base régulière et systématique, des ateliers sur les changements climatiques ayant pour but de réunir des spécialistes des sciences biophysiques et sociales pour discuter des changements climatiques et revoir les méthodes de recherche.

6) Préparer du matériel didactique visant à encourager la conservation de l'eau, la réduction des émissions de CO_2, l'intensification du reboisement, la réduction de la pollution et l'utilisation des sources d'énergie renouvelables.

LIST OF ABBREVIATIONS

AES	Atmospheric Environment Service (Environment Canada)
CAC	Climate Advisory Committee
CCC	Canadian Climate Centre
CCP	Canadian Climate Program
CO_2	carbon dioxide
GCM	Global Climate Model or General Circulation Model or Global Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory (U.S.A.)
GISS	Goddard Institute for Space Studies (U.S.A.)
ICSU	International Council of Scientific Unions
IIASA	International Institute of Applied Systems Analysis
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
K	Kelvin temperature scale (0 K is absolute zero, -273°C, or -459°F)
LAM	Limited Area Model
NCAR	National Centre for Atmospheric Research (U.S.A.)
UKMO	United Kingdom Meteorological Office
UNEP	United Nations Environment Programme
WCP	World Climate Programme
WMO	World Meteorological Organization
WUAM	Water Use Analysis Model

INTRODUCTION TO WORKSHOP OBJECTIVES

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I would like to welcome everyone to Saskatoon and especially to the National Hydrology Research Centre. We think of Saskatoon as the centre for hydrological research in western Canada. Not only is this centre located in Saskatoon, but next door we have the Saskatchewan Research Council, which has widely recognized competence in climate impact research and hydrological studies, and the University of Saskatchewan, which has an excellent reputation in hydrological research and resource economics, and good capabilities in climatology.

I am very pleased to see representation from all regions of the country at this workshop. Not only are hydrologists, climatologists and meteorologists here, but we also have a number of resource managers and experts in the social sciences and economics. I hope we can make good use of this opportunity to begin to understand each other's concerns and paradigms.

The objectives of our workshop are twofold. First, we wish to facilitate an exchange of information and views regarding Canadian studies of the impacts of climatic variability and change on water resources. The reasons for looking at the impacts of climatic change have been stated many times. It is also important to apply the results of these impact studies to our understanding of the effects of climatic variability. Resource managers are interested in knowing the potential impacts of a dry summer as compared to the impacts of two dry summers in a row. The past year (1988) was a drought year for the Canadian prairies. What would happen if we had a similar drought this summer? Would the drought from last year have preconditioned the soils, water reserves and farmer's economic conditions to the point where a second year of drought would have much more severe impacts?

Our second objective is to formulate some practical recommendations regarding the need for research and technology transfer initiatives that can be acted on by the Canadian Climate Program Planning Board. In particular, we would like to provide advice to the Board through the Socio-economic Impacts Committee on the priorities for research related to the impacts of climatic change on water supply and demand patterns. In addition there may be areas of research needs that we can identify for the Board's Research Committee.

It is not possible to discuss socio-economic impacts without understanding the physical impacts. That reasoning has influenced the structuring of the program for this workshop, which deals with physical impacts and then progresses to socio-economic impacts. I trust that this structure will not limit the dialogue between the physical and social scientists.

STRUCTURE OF THE CANADIAN CLIMATE PROGRAM

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In this review, I would like to describe the background to the Canadian Climate Program (CCP), along with its structure and its links to international activities.

In the late 1960s and early 1970s, government felt an increasing need to respond to climatological concerns. The general feeling in Canada was that, although substantial climate information, climate research, and climate application work existed, the available resources were not being utilized at an optimum level. It was believed that good coordination between all the various federal government agencies and departments, provincial governments, universities, the private sector, etc., could maximize the benefits of these resources, and hence improve Canada's economic situation. As a result, the Canadian Climate Program was formulated in 1978, with the Atmospheric Environment Service (AES) taking the lead, and on June 12, 1979, the Canadian Climate Centre was officially established.

Subsequently, the CCP began to receive endorsements from non-federal agencies. The Canadian Committee of Ministers of the Environment (CCME) endorsed the program, and provincial and territorial Climate Advisory Committees (CACs) were formed. The program now has a CAC in every region and province except Ontario.

In terms of structure, the CCP closely parallels the World Climate Programme (WCP), which was approved by the World Meteorological Organization (WMO). The World Climate Program has four sub-programs: Data, Applications, Research and Impacts. Canada also contributes to other international climate related efforts through the WMO Commission of Climatology and through the Joint Scientific Committee for the International Council of Scientific Unions (ICSU) and WMO. ICSU is the parent body for the International Geosphere/Biosphere Program. The Committee on Climate Change in the Oceans also contributes to these activities.

The WCP Impacts Program is linked to the United Nations Environmental Program (UNEP) and the International Institute for Applied Systems Analysis (IIASA). UNEP, together with WMO, is also a guiding agency for the Intergovernmental Panel on Climatic Change (IPCC). There are other international linkages; however, these summarize the major links between Canada's climate initiatives and those occurring internationally.

The Canadian Climate Program incorporates the components of the World Climate Programme into its committee structure. The CCP Board is a committee of federal ADMs which is supported by a secretariat that reports to Kirk Davson, Director of the Canadian Climate Centre. The National Advisory Committee on Data and Applications, which I chair, is the

committee to which the regional CACs report. It also acts as a focal point for the Committee of Climate Fluctuations on Man, which is concerned with paleoclimatology, and for a newly formed committee for Forest Climatology and Meteorology.

There is also a research committee, chaired by Kirk Dawson. A sub-committee that deals with modelling reports to this committee, which makes recommendations to the CCP Board on areas where it feels there is a priority for research on the impacts of climatic change. The Canadian Climate Centre is responsible for coordination and staff support to various committees, and for providing expertise to various studies.

In addition to publishing the results of research studies (e.g., the Climatic Change Digest series), the CCP also provides financial support to other organizations. It has supported two industrial chairs at universities in Canada, one at McGill (modelling) and another at Dalhousie (marine meteorology and climatology). It provides support for the committee activities, for regional initiatives, and travel funds for people to attend committee meetings. The CCP also co-sponsors workshops across Canada and the U.S., including the Great Lakes U.S.A./Canada Symposium that was held in Chicago last year.

On an international level, Canada is an active member of WMO and the World Climate Programme both in research and other activities. Other recent examples of support include financial assistance for the Quebec Climate Association and the national carbon dioxide (CO_2) monitoring program. Of course the Canadian Climate Centre, which is an integral part of this program, is also supporting climatic research through its GCM modelling work and climatic trend studies.

In conclusion, let me assure you that as the CCP enters its second decade it is a strong, vibrant program, and will continue to provide leadership for climatic research for many years to come.

SIMULATION OF EQUILIBRIUM CLIMATE CHANGE RESULTING FROM INCREASED CARBON DIOXIDE USING GLOBAL CIRCULATION MODELS

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Atmospheric global circulation models are designed to simulate the atmospheric climate in three spatial dimensions. These models are based on the physical equations governing the motion and thermodynamics of the atmosphere and include, either explicitly or parametrically, all of the important physical processes that determine its evolution and structure on synoptic and larger spatial scales.

Because of their size and complexity, such models are expensive to use, both in terms of human and computer resources. However, this complexity results from the attempt to achieve a realistic mathematical modelling of the atmospheric climate. Consequently, despite their costliness, such models are valuable tools for studying the climate change that may result from anthropogenic alterations to atmospheric composition. The problem of estimating the climatic effects of increased amounts of greenhouse gases in the atmosphere is of physical interest in this regard. It is also of economic and social importance in view of the large (and accelerating) enhancement of carbon dioxide (CO_2) that has occured since the beginning of the industrial revolution. In recent years this has motivated a considerable amount of research using atmospheric general circulation models to address various aspects of this question.

To date five different modelling groups, four in the United States and one in the United Kingdom, have carried out and compared simulations of the equilibrium climate associated with current and doubled concentrations of carbon dioxide in the atmosphere. In all of these studies, the oceanic component is a simple mixed layer of fixed depth in which internal transports are either ignored or specified.

Although the models used by these groups have all been carefully designed, there are differences between the equilibrium climates simulated with them. Such differences are due largely to the fact that many of the important physical processes that are included in the models cannot be explicitly resolved and must therefore be parameterized in terms of those quantities that are resolved. The coupling between resolved and unresolved processes is still imperfectly understood and hence the latter are sometimes represented differently in different models. Thus it is desirable that climate simulations of this sort be carried out by several different modelling groups. Communication and inter-comparison of results between modelling groups often lead to resolution of such uncertainties.

Despite their differences, there are broad areas of agreement in regard to changes in the equilibrium climate that may accompany a doubling of CO_2 amounts. Thus, while all the models simulate a net (globally averaged) warming at the surface, the magnitude of this varies between 2 and 5 K, and the horizontal distribution of the surface temperature changes differs between the models. In a broad sense, the main results of those simulations, classified as to the degree of agreement between the models, can be summarized as follows:

1) When CO_2 is doubled, all of the simulations indicate that the troposphere warms, the stratosphere cools, and the global water cycle is enhanced. All models of comparable spatial resolution indicate that the warming is largest in high latitudes and relatively larger in winter. The warming is smallest in the tropics and has relatively less seasonal variation.

2) All models of comparable spatial resolution indicate that seasonal sea ice melts earlier and forms later. The simulations made with this group of models also agree in general in indicating that soil moisture is higher in middle to high latitudes in winter.

3) Some, but not all, of the models indicate that the seasonally varying snow mass accumulates later and melts earlier in the year. In some of the simulations, soil moisture amounts decrease in middle and high latitudes in summer.

A recently improved version of the atmospheric general circulation model developed in the Canadian Climate Centre is now being used to simulate the equilibrium climatic response to a doubling of carbon dioxide. It is expected that results from this work will become available early in 1990. This study has been initiated in part because the possible consequences of the climate changes associated with increased CO_2 are of great concern to Canada in view of its northerly location and sensitive ecosystems. However, the study was also undertaken in part to provide a contribution to the international research effort on this topic.

POSTSCRIPT (January 1990)

The Canadian Climate Centre simulations of equilibrium climate for current and doubled CO_2 have recently been completed. Results are now being analyzed and prepared for publication. Preliminary analysis indicates that the simulated climate changes are in broad agreement with those obtained by other modelling groups. In particular, on average, global warming of approximately 3.5 K was indicated as the response to doubling of CO_2. As in other simulations, this response is relatively larger in high latitudes and in winter. Other aspects of the results will be reported in forthcoming papers.

NATIONAL WATER RESOURCE IMPLICATIONS OF POSSIBLE CLIMATIC CHANGE IN CANADA

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The significance of global climatic change in relation to Canadian water resources is formally recognized in the Federal Water Policy, released in November 1987. Furthermore, climatic change is unique among the many water-related concerns specified in the Policy document in that its potential impacts are likely to affect efforts to address practically all of the other main issues, from drought and flooding to water quality and water use.

The planning and management of water systems has been traditionally based on the assumption of unchanging climate. The projected time scale for realizing significant climatic change (that is, global warming of from 1.5 to 4.5°C by 2050) is similar to that required for planning and developing large-scale water management systems. Given such a scenario, there exists an urgent need to assess the effect of the climatic change factor on water, water use and water users in Canada.

Changes in evaporation and precipitation caused by global warming would result in direct impacts on the magnitude and timing of water regimes throughout Canada. Furthermore, sea-level rise enhanced by global warming would have significant effects on Canadian maritime environments and coastal freshwater resources. Long-term climatic change would affect hydrologic characteristics such as mean annual streamflow, annual flow variability, seasonal supply distribution, as well as the frequency and intensity of extreme events. Changes in water demand patterns both in human use and natural requirements would compound supply uncertainties. Accelerated sea-level rise would flood low-lying urban and agricultural lands and contaminate freshwater supplies and delicate ecosystems. The cumulative effect of these changes would be most meaningful at the watershed level and, therefore, sensitivity assessments relating climatic change to water resources must be conducted at the regional scale.

Climatic change impacts on the water resource sector will be most significant in areas of Canada where natural and human environments are already sensitive to climatic and hydrologic variability. These include regions with high probabilities of water demand exceeding local supply in

general, and in terms of sea-level rise, low-altitude coastal lands. Potential trouble spots among major drainage basins in Canada, where net water use is relatively high compared to annual reliable flow without factoring in a climatic change effect are the Missouri (Milk), South Saskatchewan, Assiniboine-Red, and Okanagan. Large sections of the Canadian Arctic, Atlantic and Pacific coastlines are at risk of impacts resulting from enhanced sea-level rise.

Canadian case studies of the potential hydrologic impact of climatic change have been based almost exclusively on the scenarios produced by the state-of-the-art general circulation models (GCMs). These are sophisticated global models that attempt to simulate complex natural systems. While they are constantly being improved, the GCM output is not yet fully adequate for describing the regional characteristics of the expected climatic change. In particular, hydrologic processes such as precipitation, evaporation and cloud formation occur naturally at finer scales than those used for the GCM data networks. Furthermore, hydrologic changes predicted by GCMs are based on greatly simplified simulations of the actual process and are therefore highly uncertain at the regional scale.

Some interesting Canadian work has been done on the potential impacts of climatic change on water resources and related socio-economic activities, despite the limitations and uncertainties of GCM scenarios. Modelling procedures and scenario development of varying complexity have been applied to selected drainage basins with a wide range of results that sometimes differ considerably for the same study area (Table 1). Translating these hydrologic scenarios into socio-economic impacts provides an indication of the sensitivity of human activities to the expected biophysical changes. For example, net annual benefits of from 61 to 92 million dollars (1984) and from 595 to 708 million dollars (1987) were estimated for hydroelectric production on the Great Lakes and in the James Bay region respectively. For the Great Lakes region, annual savings from reduced energy demand (with higher temperaures) would exceed annual costs of replacing reduced generation (less water). In addition to annual savings from reduced energy demand, more water in the James Bay region would increase annual pover generation and sales. On the negative side, the average annual costs of Great Lakes shipping would increase by 30% and, in general, thousands of water-using industries employing hundreds of thousands of workers in the Great Lakes region would be affected adversely by predicted reductions in available water supply.

Assessment studies of enhanced greenhouse warming and its effect on mean sea levels around Saint John, New Brunswick, indicate that the existing 1:100-year level for storm surge and river flooding would become a 1:20-year line, resulting in more frequent and extensive extreme event impacts. Salt-water intrusion would contaminate groundwater aquifers (the main source of regional water supplies), disturb sensitive estuary ecosystems, and displace freshwater fish populations. Options for responding to these types of impacts include expensive reconstruction of existing infrastructure and construction of new protective mechanisms. For example, American experts estimate that the cost of upgrading an Atlantic sea wall to withstand a one-metre rise in mean sea level would be 50% higher than rehabilitation costs under current conditions. Sea-level rise enhanced by a warmer climate would increase significantly the probability

Table 1 **HYDROLOGIC EFFECTS OF CLIMATE CHANGE SCENARIOS FOR CANADA**

AUTHOR	REGION	DRAINAGE AREA ($km^2 \times 10^4$)	CLIMATIC CHANGE (approx.)			HYDROLOGIC CHANGE (approx.)	
			T (°C)	P (%)	GCM	Runoff (%)	Other
Southam and Dumont (1985)	Great Lakes	76.0 (32% is lake surface)	+4.5	-3 to +8	GISS/84		Levels (cm) -21 to -99 Flows (%) +2 to -13
Cohen (1986a, 1987a)	Great Lakes	76.0	+3.1 to 3.7 +4.3 to 4.8	+0.8 +6.5	GFDL/80 GISS/84	-8.2 -10.9	Supply (%) -18.4 Supply (%) -20.8
Singh (1988)	James Bay	17.5 (18% is lake and reservoir surface)	+3.5 +4.7	+17.5 +15	GFDL/80 GISS/84	+10.9 +15.7	Supply (%) +13.9 Supply (%) +16.1
Singh (forthcoming)	James Bay	17.5	+3.5 +4.7	+17.5 +15	GFDL/80 GISS/84	+8.3 +15.7	Supply (%) +8.9 Supply (%) +22.6
Cohen, Welsh and Louie (1989)	Saskatchewan River	36.4	+2.5 +4.4	+18 +19	GFDL/80 GISS/84	-58 +37	Supply (%) -65 Supply (%) +38
Haas and Marta (1988)	S. Saskatchewan River	15.7	+2.5 +4.4	+18 +19	GFDL/80 GISS/84	-20 +28	
Ripley (1987)	Arctic Atlantic Gulf Hudson Pacific Canada	331.0 151.0 3.0 356.0 94.0 935.0	+2 to 3.5 +2 to 3.5 +2.5 to 3 +2 to 4.5 +2 to 3 +2 to 3	+54 +11 +23 +17 +23 +23	UKMO/83 UKMO/83 UKMO/83 UKMO/83 UKMO/83 UKMO/83	+95 +10 +235 +20 +20 +32	

of flooding impacts on waterfront sevage and industrial vaste facilities in Canadian maritime communities such as Charlottetovn. At risk are waterworks and wastevater systems vith replacement values of 3.1 billion and 2.4 billion dollars (1985) respectively.

The scientific consensus on climatic change is that if current increases in atmospheric greenhouse gases continue, during the next century a rise in global mean temperature could occur that is larger than any experienced in human history. Many uncertainties remain regarding global climatic change and regional hydrologic impacts. These information gaps may not be fully resolved in time to effectively deal vith the expected impacts, the result being missed opportunities for adequate responses and thus, unnecessary economic and social costs. In terms of responding to possible climatic change, limitation strategies cannot prevent all causes and impacts. Similarly, adaptation strategies cannot accommodate the implications of unrestricted climatic change. Therefore, some of both strategies vill be required.

Water planners and managers must begin factoring in the possibility of climatic change by focusing efforts on the coping ability of water systems and vater users. Emphasis should be placed on the systematic assessment of regional vulnerability and resilience. Strategies for coping vith the stresses of climatic change should include the application of concepts such as the persistence, elasticity, reliability, and adjustability of both hydrologic and socio-economic systems. These are not radical nev concepts, but are water planning and management options that make sense nov, even without the likelihood of climatic change. As climate protection legislator John Chafee so aptly stated in 1988: "We lose so little by trying; ve may lose everything by doing nothing."

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UNCERTAINTIES AND ISSUES IN WATER MANAGEMENT IN THE GREAT LAKES BASIN

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INTRODUCTION

Climate change, which has become increasingly evident over the past few years, is the prime contributor to the fluctuating levels of the Great Lakes.

Due to this possible climate change, there are some water management issues in the Great Lakes area that have surfaced or will do so.

GREAT LAKES OBSERVATIONS

In response to record high levels of the Great Lakes in the decade leading to 1985, which resulted in shoreline flooding, erosion, and property damage, pressure on the International Joint Commission (IJC) and government to have the Great Lakes levels modified was initiated by the International Shore Owners Coalition. As a result, the Great Lakes Water Level Communication Centre was opened and the issue was examined by the IJC.

THE GREAT LAKES FOCUS

The high levels of the Great Lakes were caused by a 20-year period of above average precipitation, which ended in 1985, after which levels began to drop.

Despite record high temperatures in 1988, precipitation remained above the 20th century average. However, as precipitation in the winter and spring months was abnormally low, a seasonal shift in the distribution of the precipitation became evident.

During the combined years of 1987-88, precipitation was moderately above the period of record average, but lake evaporation had increased, net basin water supplies decreased and lake levels decreased with an earlier seasonal peak due to higher air temperatures.

WHAT DOES CLIMATE CHANGE MEAN TO THE GREAT LAKES BASIN?

Possible water related impacts:

- Loss of hydropower production;
- Water temperature and water quality problems for water-cooled fossil fuel and nuclear power plants;
- Increased costs of commercial shipping on the lakes;

- Impacts on wetlands;
- Impacts on recreational boating, marinas, and waterfront property;
- Increased dredging needs;
- The failure of present lake level regulation plans on lakes Superior and Ontario;
- Impacts on infrastructure and increased water user conflicts.

Increased pumping of Great Lakes water for municipal supplies, or from ground and surface waters in the watershed for irrigation, reduces Great Lakes levels and flows.

MANAGEMENT ACTIONS

While the most important action to be taken requires the reduction of greenhouse gases, from a water management perspective the following actions can be taken:

- Place continuing emphasis on hydroelectric power generation;
- Look carefully at water pricing in the infrastructure sense, and general conservation measures;
- Promote water recycling, more efficient irrigation and a water withdrawal permitting system;
- Continue to apply the Canada - U.S. agreement on water use and apportionment for the Great Lakes;
- Develop new regulation plans for lakes Superior and Ontario;
- Continue discussion about diversions, centring on diversions of Great Lakes water to the U.S. Midwest;
- Develop emergency water management measures in preparation for expected drought conditions, and solicit ideas of expected change in the probability of extreme storm and drought events.

CONCLUSION

Climate change may come too quickly for society to adapt. Therefore, management strategy based on "anticipate and prevent," supported by elements of mitigation and advanced planning for adaptation is necessary.

UNCERTAINTIES AND ISSUES FOR WATER MANAGEMENT IN WESTERN CANADA

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The prairie economy and society have always lived with a variable climate. Alternating years of flood and drought are more the norm in the Prairies than the rest of Canada. Climate change adds a further dimension of variability and uncertainty; and it is within this context that the implications for climate change should be assessed.

Broadly speaking, in the last 10 to 15 years, the region has experienced four drought (1976-77, 1980-81, 1984, 1988) and four flood (1976, 1986, 1988, 1989) years. The year 1988 was a year of both flood and drought within sub-regions of the Prairies.

Irrigated agriculture (which comprises less than 1% of the total of 56 million hectares under cultivation, but amounts to 15% of agricultural production) and the thermal power sector dominate the economy in terms of water use. Together they account for about 82% of water use in terms of water withdravals. Municipal and industrial use constitute equal shares of the balance. In terms of water consumption, irrigated agriculture is the dominant force (60%) with reservoir evaporation at 30%. Conceptually, the latter consumptive use should be shared by irrigation, hydro power, and municipal and industrial use in terms of their share of total reservoir area.

Water use data extracted from the Prairie Provinces Water Board (1982) indicate that for both irrigated agriculture and thermal power generation, water use has expanded significantly from the early 1950s to the late 1970s. Acreage under irrigation in Alberta increased almost three times and water use in the range of six times over this period. With the establishment of the South Saskatchevan River project in the late 1960s, irrigation also became established in Saskatchevan, but still is small (only about 5%) compared to Alberta. Water use in thermal power increased in similar orders of magnitude over the same period.

If these trends continue to the turn of the century, water use, both in terms of consumptive use and withdravals by major basin of the Prairies (Environment Canada 1984), could equal the available water supplies. In terms of consumption, there appears to be some "room for comfort," as an extreme low supply scenario (50% of lovest natural flow) approximates the forecast water consumption in the major basins. In terms of withdraval forecasts, this flexibility vanishes, posing perhaps serious issues for maintaining instream flows in crisis, low-flow years.

The Cohen, Welsh and Louie study (1988) applied major climate change models to the Saskatchewan River Basin. These results can be viewed as "enveloping" the supply possibilities, such that net supplies could increase by one third, or decrease by two thirds. For the former scenario, the shortage issue, especially with respect to instream flows, would be ameliorated. However, for the latter the implications would be serious. The "room for comfort" would be reduced and the stress on instream flows would be increased considerably. With climate change the "room for comfort" could also be diminished by increased consumptive use of supplies through increased reservoir evaporation and increased water use.

CONCLUSIONS AND RECOMMENDATIONS FOR MONITORING AND RESEARCH

1) Economic development is approaching the limit of water supplies. Continuation of present trends in water use and development, in terms of the use of remaining supplies, may constrain the region's ability to cope with a more variable and/or perhaps drier climate posed by climate change over the long run. Flexibility and adaptation to changing circumstances will be the key.

2) It appears that the rate of growth of irrigated agriculture and thermal power development from the 1950s to the present cannot be sustained into the future if climate change noticeably reduces runoff. Other present uses, especially instream uses, may be constrained in terms of their current level or with respect to options for expansion. These implications need to be addressed within a water use-economic model that can assess the economic consequences of such a climate scenario.

3) Monitoring and research into the implications of climate change for water use in agriculture should be initiated, with the view of assessing water requirements for crop types under various climatic regimes, and developing means to conserve water. For the thermal power sector, the financial and economic implications of water conservation alternatives that may be required to meet the range of climatic extremes in the future should be investigated.

4) More intensive management of water, interprovincial cooperation in coordinating future plans, and development terms of water supply and quality impacts on basin management are likely to become necessary if climate change leads to reduced water supplies. Long-term availability of reliable water supplies of acceptable quality is essential to achieve economic diversification and environmental quality goals. This issue needs to be addressed at an interprovincial level. Steps needs to be taken now to develop a coordinated approach to ensure sustainable economic growth for the region as a whole.

5) The data base on streamflow, water level, climate, water use, and water quality needs to be upgraded and expanded, considering the value of water and need for more intensive management in the future.

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OVERVIEW OF METHODS USED IN ASSESSING THE IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

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I was asked to provide a broad overview of methods for water resources impacts studies. This requires consideration of four major elements, linked in sequence. They are

1) climate change scenarios
2) hydrological processes
3) water resource systems
4) society

Although certain generalizations are possible, it must be noted that at the regional scale, individual watersheds have unique features necessitating the design of region-specific research frameworks. Space does not permit the inclusion of much detail, but this overview should set the stage for the presentations to follow.

There are a number of methodological concerns that affect regional impacts research, including mismatch of scales, application of climate scenario data, modelling and projection of climate-society linkages, and projections of non-climate factors.

A wide range of scenarios have been used in impacts work, including various types of GCM outputs. The most commonly used are from steady-state models [$(4 \times CO_2)/2$ and $2 \times CO_2$ experiments]. Transient models (from Goddard Institute for Space Studies, or GISS), which have only been available for a short time, were used in several U.S. studies. Limited Area Models (LAM) with much finer resolution are being developed, but are not yet available for impact work. Other types of scenarios include analogues (paleo and instrumental) and hypothetical cases.

All scenarios (including hypothetical) require a baseline. At the present time, GCMs cannot reproduce regional normals, so how should this baseline be obtained? Present practice is to use a standard set of normals, e.g., 1951-1980. However, GCMs are not produced on the same grid, and different grid networks may produce different regional normals. It is suggested that all scenarios and normals use a common grid so that only one baseline set needs to be generated. This means that interpolation of GCM output will be unavoidable until fine resolution LAMs become available.

It is also important to consider the issue of representativeness, i.e., will the normal and scenario data represent a point or a grid square? Since the GCM-based scenario values represent grid squares, one must be careful about assuming that a normal for a point represents the square. This may be reasonable for some squares, but may not be if there's mountainous terrain, etc. This uncertainty regarding data can affect validation of models that use climatic data as input.

The conventional application of GCM-based scenarios to baseline data is as follows:

$$\text{Temperature: } [(2 \times CO_2) - (1 \times CO_2)] + \text{"normal"} \quad (1)$$

Precipitation, wind speed and other elements that cannot be negative are treated as follows:

$$[(2 \times CO_2)/(1 \times CO_2)] \times \text{"normal"} \quad (2)$$

If the denominator is 0, modellers have suggested deleting that point, and using interpolation from neighboring points.

There has not been much experience with elements other than temperature and precipitation, but as users become more familiar with GCM output, and as LAMs become available, there will be increased use of these outputs (e.g., wind, humidity). If one is interested in runoff, a question arises regarding the use of GCM runoff output, as opposed to using precipitation output to generate runoff separately. For now, there appears to be a preference for the latter.

Due to coarse resolution of present generation GCMs, all continental grid points are classified as land. In most GCMs, there are no water points over the Great Lakes and other large inland water bodies (an exception is Hudson Bay). Thus, no output is available for lake temperature, lake evaporation, lake effect precipitation, lake ice, etc. Similar problems are encountered for mountainous terrain and vegetation boundaries.

A number of methods have been used for assessing regional impacts for the land portion of watersheds, resulting in estimates of runoff, soil moisture, water use and other parameters. These include direct use of output from GCMs for runoff and soil moisture, and the application of separate models using scenario data on temperature, precipitation, wind speed and energy balance parameters. Some examples of these modelling approaches are

- Thornthwaite climatic water balance (e.g., Great Lakes, California, Saskatchewan River)
- Other water balance equations derived from Thornthwaite (e.g., U.K., U.S., Great Basin)
- Penman-Monteith energy balance model for evapotranspiration (e.g., U.S. sites)
- Analogue (e.g., U.K. streamflow)
- Empirical/statistical (e.g., western U.S., Colorado River, Great Lakes water use, Saskatchewan River water use)

There are fewer examples of case studies for the water portion of basins. These have included estimates of open water evaporation and over-lake precipitation. Evaporation estimates have been obtained from

- mass-transfer model (e.g., Great Lakes)

- mass-transfer combined with ice and heat storage models (e.g., Great Lakes)

- Priestly-Taylor energy balance model (e.g., James Bay)

Basin or system approaches have also been used to estimate changes in runoff, snowmelt and other hydrologic parameters. These include integrated models, such as

- conceptual system-based (e.g., Sacramento Model, IRMB from Belgium)

- tank-cascade (e.g., Great Lakes Large Basin Runoff Model from the U.S.)

In addition, hydrologic routing models have been used to assess changes in lake levels (e.g., Great Lakes). These are initiated by new values for net basin supply, etc., from other models. Stochastic approaches are being used to simulate climate and streamflow records (e.g., Mackenzie Valley). Finally, separate land and water model outputs have been combined to produce estimates of net basin supply (e.g., Great Lakes, Saskatchewan River).

Space does not permit an extensive review of methodologies for doing socio-economic impacts research. However, it is noted that a range of approaches are being used (e.g., a single sector, hierarchy of models, regional input/output models). The earlier links in the climate-water resources chain provide three starting points for socio-economic research:

- Changes in hydroclimate affecting shipping, hydroelectric production, etc. (e.g., lake levels, net basin supply)

- Changes in water quality affecting fisheries, water treatment for various uses, etc. (e.g., water temperature, dilution potential)

- Changes in climate affecting water use for irrigation and other climate-sensitive sectors (e.g., summer air temperature).

This brief overview of the application and development of climate change scenarios for regional impacts work has raised a number of issues, which are summarized as follows:

1) Due to uncertainties in baseline data, there is a need for improved monitoring in remote areas, large inland waters and complex terrain;

2) During the present "pre-LAM" phase of GCM-based scenarios, interpolation will be difficult to avoid and there will continue to be a need to generate data separately from the GCM. Once the "LAM" phase arrives, more scenario data could be obtained directly from GCMs (including baseline?);

3) Regarding other climate scenarios, GCMs will probably continue to be the reference for scenario design (due to questions regarding boundary conditions in other scenarios);

4) A wide range of approaches are available to do water resources impacts work, but data limitations can affect model application and validation.

It is also useful to place the above efforts in the broader context of climate-related research. What is the "mission" of regional impacts work? I feel that the mission is to bring the global warming issue to the regional level in an objective and quantitative manner. A number of major constraints have been identified above. However, if this is an appropriate mission to pursue, there are certain things that regional impacts work can do now. I feel that it can identify general sensitivities, data gaps and research needs, and raise awareness of potential problems "close to home," although this depends on our ability to get an accurate message to decision makers and the public. What regional studies cannot do yet is provide recommendations on specific existing and proposed systems/policies (beyond generally accepted principles, such as pollution reduction, enhancement of system flexibility and promotion of improved energy efficiency). What is needed is direct input from regional managers/system operators/policy analysts. In addition, regional studies will not be able to provide forecasts until there are scenarios (climate and non-climate) that are more reliable, and until we have more complete understanding of the linkages between climate change/variability and regional physical and social processes.

Regional impact study is a long-term multidisciplinary and interdisciplinary research issue. The development and application of scenarios is an important part of this. We need to take inventory, consolidate what we know, and get more involvement from regional interests. This is beginning to happen in the Great Lakes region, where several years of case studies have culminated in a recently held international symposium on Great Lakes impacts. Today's seminar is timely since it can contribute to similar efforts in the rest of Canada.

POSSIBLE HYDROLOGICAL IMPACTS OF CLIMATE CHANGE IN WESTERN AND NORTHERN CANADA: METHODS AND FINDINGS

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Due to the recent occurrences of drought on the Canadian prairies, there is particularly strong concern about the possibility that CO_2-induced climate warming may lead to the increased probability of drought. Hydrologists need input from climatologists in order to be able to estimate surface runoff, available soil moisture, ground water, etc. There are several possible ways to develop climate scenarios for the future. One approach is to use historical analogues; unfortunately, past climates, even if warmer, may not mirror the expected warmer future climate because of differences in forcing characteristics. Further, there is a lack of detailed information on past climates. Although some climatologists resort to "educated guesses," the most common approach has been to use the output of Global Climate Models (GCMs), run with doubled CO_2 concentration.

GCMs provide the best scientific basis for preparing climate scenarios of the future. However, the limitations of climate models must be recognized. First, GCMs contain only imperfect representations of many processes. The parameterization of land-surface hydrology in terms of "bucket" of uniform capacity regardless of soil conditions is one example. GCMs are very sensitive to the cloud-radiation feedback processes and further research is needed. No GCM presently includes the oceans in a fully interactive way. Second, due to their imperfections, not all GCMs simulate the present climate very well, even though many of the parameterizations are adjusted to fit the present climate. The third issue is the horizontal resolution of GCMs. The grid spacing in most models is between 4 and 10 degrees of latitude or longitude. Since it takes about four grid distances to simulate a physical feature, information on smaller regional scales is not available in GCMs. Hence, GCM results should only be used for large-scale features.

A suggested approach for the use of GCMs in hydrological studies is the following. Recognizing that GCM results have uncertainties and are scenarios of the future, not predictions, it is appropriate to choose the results from the models with the best spatial resolution (at present, NCAR, GFDL, UKMO). Because of considerable uncertainty in the role of the oceans, the results from transient simulations should be used with extreme caution. Instead, the equilibrium doubled-CO_2 results should be adjusted to allow for an approximately 50-year lag of the upper ocean behind the CO_2 concentration. First-order variables (wind, temperature, precipitation) should be used; soil moisture and runoff in models are residuals that accumulate errors. Only the results for large scales should be used; average over several grid areas. Given the outputs of say three GCM scenarios, the results should be considered in terms of "risk assessment"; how would your strategy change if these climates occurred? For

hydrological purposes, the first-order variables can be inserted into physically based (not empirically derived) models to deduce the changes in, for example, streamflow in given areas. By following this kind of approach the advantages of the GCMs can be gained without misusing their results.

POSSIBLE IMPACTS OF CLIMATE CHANGE IN EASTERN CANADA

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There have been a number of studies funded by the Canadian Climate Centre to investigate the potential impacts of a climate warming on the Canadian economy. Most of these studies used the 2 x CO_2 scenarios adopted from the outputs of two U.S. General Circulation Models, one developed by the Geophysical Fluid Dynamics Laboratory (GFDL) and a model developed by the Goddard Institute for Space Studies (GISS). Researchers used outputs from these models as scenarios and developed further "predictions" about the physical climate using relations such as the Thornthwaite technique for estimating soil moisture conditions, water surplus and therefore runoff. These outputs were then taken a step further and applied as inputs to socio-economic models. A summary is provided below of some of the results of these studies.

In a scenario for Atlantic Canada, the annual temperature increases by 4.0°C in the Maritimes and Newfoundland and by 4.7°C in Labrador. Average annual precipitation has a 2 to 3% decrease in Maritimes but a 5.9 to 7.5% increase over Newfoundland and Labrador respectively. Runoff calculated through the use of water-budget techniques decreases by 20% over the Maritimes, but is increased by 35% over Labrador. At the same time, there is a rise in sea level of approximately a metre; sea surface temperatures are increased by 2 to 3°C, with speculation that there would be a stronger Labrador current and decreased surface salinity of the shelf waters with reduced or absent sea ice south of Labrador. The findings of the studies indicated that there should be a growth of the aquaculture industry, there could be a longer inshore fishing season, but that over-capacity or fish quota problems would likely be exacerbated. The region could benefit from reduced ferry and icebreaking costs, but this gain would be reduced by the loss of winter marine traffic to Churchill, Montreal and Seaway ports. Offshore oil and gas downtime due to ice might be practically eliminated, a $40 million saving in terms of 1984-85 activities. Damage to coastal infrastructure from sea level rise, however, might be extreme, with costs up to several billions of dollars. Hydroelectric capacity would be increased in Labrador but reduced elsewhere. This would be a net gain in power capacity for the region, however, there would be no net gain financially because of the contractually low revenues from energy sold to Quebec.

In Quebec, the average temperature increases range from 2.5 to 3°C in the warmer months to 6 to 7°C in the winter. Average precipitation is essentially unchanged in the southern parts, but there are large discrepancies in the north between the GISS and GFDL scenarios. There, precipitation departures range from 10% to 100% above normal. Computed runoff from three major James Bay basins is increased: GFDL by 13.9%, and GISS by 16.1%. Generating capacity is increased by 15%, but Montreal and Quebec City heating energy requirements would be reduced by 25% and 35%

respectively. Growing degree days are increased by 40% to 105% and thus grape and apple growing areas could expand. However, there could be greater dependence on irrigation in the south. As a result of changes in permafrost, tundra ecosystem areas could be reduced by 62 to 100%. In summary, there would be mostly benefits for Quebec from such scenarios.

In Ontario, the mean annual temperature increases by 4.3 to 4.8°C, cloud coverage decreases slightly (2.3%) but annual precipitation is increased by 6.5% (generally more in winter, but slightly less in summer in the southeastern Great Lakes basin). Average ice cover is eliminated on all the Great Lakes except for Lake Erie, which would still attain a 50% maximum coverage, because of its shallowness and fast response to winter temperatures.

By applying the Thornthwaite technique, the net basin supply to the Great Lakes is computed to decrease by 15%, and Great Lakes levels by as much as 80 cm if increased consumptive uses are considered.

The reduced flows and levels could be expected to have a negative impact on water quality and the function of wetland ecosystems. Costs of carrying bulk cargoes (iron ore, grain, coal and limestone) would be increased by 30%. Energy demands may be reduced by 2 to 3% (a saving of $172 to 204M, 1984$), but hydro power capacity (Sir Adam Beck and Moses Saunders) would be reduced by 20% ($111M loss) for a net saving of $61 to 92M annually.

CRITIQUE

All of the above results make use of the results of Global Circulation Models (GCMs) to develop temperature and precipitation scenarios under CO_2 warming. It is noted that the differences between model scenarios (GISS, NCAR and GFDL) for 1 and 2 x CO_2 for various temperature, humidity and energy balance fields is generally greater than the changes one is trying to estimate. The Great Lakes do not exist as far as the models are concerned. Moreover, because of the very lov resolution possible with GCMs, impacts modelers are forced to apply these coarse differences in fields of changed climate parameters to the existing climate. Further inaccuracies could arise when an empirical model such as the Thornthwaite technique is applied. This technique applies with the present day temperature regime and may not necessarily hold in a changed climate. Physically based impacts models are recommended for impacts work.

EFFECTS OF CLIMATE CHANGE ON

WATER QUALITY IN CANADA

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Atmospheric models are predicting changes in climate that will affect regions of Canada to varying degrees. These changes will affect Canada's water resources and subsequently will lead to changes in water quality. Changes in climate predicted include the following:

1) Temperature increases, particularly in northern Canada
2) Variability in precipitation patterns
3) Increases in precipitation, particularly in the north
4) Drier summers in mid-latitudes
5) Increases in evapotranspiration
6) Warmer winters, less snow cover
7) Reduced soil moisture

Using these predicted changes an assessment of the possible impacts on three regions is considered.

PRAIRIE PROVINCES

Although there could be an increase in precipitation, this would be more than offset by an increase in evapotranspiration as summer temperatures rise by 1.5°C. There could be large reductions in spring runoff. Reduced runoff would mean less particulate transport of nutrients and also pesticides. Rivers would definitely become more saline especially with greater demand on the available water for irrigation purposes. Point and diffuse loadings would be more concentrated due to reduced water availability.

In summary, the Prairie provinces would become drier and more drought prone. Water quality would degrade, possibly to the point where the water would be unsuitable for some uses without prior treatment.

GREAT LAKES/SOUTHERN ONTARIO

There are predictions of increases in precipitation and in evapotranspiration with the net result being reduced runoff to the Great Lakes. Mean daytime temperatures are expected to rise several degrees.

In terms of water quality impacts, the reduced runoff will mean lower lake levels, longer retention periods and reduced flushing. The period of stratification would be lengthened. This could lead to increased anoxia. With the temperature increase there could be more frequent algal blooms. This could increase problems for water intakes. There would also be a concentration of point source loads.

NORTHERN CANADA

Predictions for northern Canada include substantial increases in precipitation, increases in evapotranspiration and warmer temperatures, especially in winter.

For water quality, the potential large increases in spring runoff will cause increased transport of particulate material into the rivers. There will be increased erosion by rivers. The loss of permafrost in some areas could increase runoff. The increased temperatures will lead to increased productivity in lakes and streams.

The changes in water quality mentioned above are projections based on climate change scenarios. At this time it is very difficult to accurately assess what could happen. As climate models become more refined we should be able to give better estimates.

METHODS FOR MODELLING ECONOMIC IMPACTS OF CLIMATE VARIABILITY AND CHANGE

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There are several links between the impacts of climate change arising from a doubling of CO_2 and economic activities:

1) Energy use leads to higher concentrations of CO_2 in the atmosphere
2) Changes in climate variables such as temperature and precipitation
3) Impacts on hydrology (e.g., runoff, soil moisture)
4) Impacts on biophysical environment (e.g., wetlands, forests, fisheries)
5) Impacts on economic activities.

This long chain of linkages produces several layers of uncertainty.

There are several economic methodologies that could be fitted into the more established approach to climate impact analyses, e.g., benefit-cost analysis, input-output analysis, linear programming, integrated models of economic production such as farming, as well as methods used in hazards research. Regional integrated assessments would provide a practical framework for testing and enhancing the usefulness of these analytical approaches.

Most research efforts have focused on biophysical aspects of climate change. Contributions from politics and the humanities are fitted into an agenda set by biophysical science. Does our way of currently specifying the climate change issue affect the type and the findings of social and economic research in this field? At least the policy implications of this pattern of research merit fuller consideration. In addition, we need to explore the context within which environmental risks such as climate variability and change are expressed as significant issues. For example, would climate impacts be less significant if most people became vegetarians? In brief, we need to focus on vulnerabilities and on how to enhance resilience in our policy response. We need to identify adaptive management options that make sense whether the climate changes or not.

In brief, we have a twofold challenge: we need to produce more and better studies of economic impacts of climate change on a sector-by-sector basis, and we need to broaden our investigations to include more integrated regional assessments and contextual analyses. This interdisciplinary workshop is an encouraging step towards identifying research needs in a fast growing field.

TRANSLATION OF HYDROLOGIC DATA AND PREDICTIONS INTO SOCIO-ECONOMIC IMPACTS--METHODS/MODELS

Bruce McClennan
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Acres International Limited
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The purpose of this presentation was to discuss the Water Use Analysis Model (WUAM) and ways it could be useful for the study of climate change.

A figure was presented which showed four classes of change resulting from long-term shifts in the primary climate variables: precipitation, temperature, and evaporation. The changes discussed all lead to some form of socio-economic impact.

1) Direct process changes--These refer to changes in the biophysical environment as a direct result of changes in climate. Shifts in rain-fed agriculture and in forestry as a result of precipitation and temperature change are two good examples.

2) Hydrologic changes--The quantity and timing of supply of both surface and ground water will change as a result of shifts in the primary variables. Currently, there is considerable research aimed at forecasting water supply in an altered climate environment.

3) Water demand changes--Demand quantities and patterns will change in all water-using sectors: agricultural, industrial and municipal.

4) Socio-economic changes--Some socio-economic changes will result from shifts in the primary variables. For example, people will be redistributed because global warming will make some areas more habitable than at present. Other significant redistribution may well occur as a result of impacts to other secondary changes such as the shifts in agriculture.

WUAM is perceived as a potentially valuable tool in climate change research in that it combines the impacts of 2 and 3 above and incorporates elements of socio-economic change such as population growth and redistribution.

The assessment of present and projected water demands and water availability for multipurpose use in the country, particularly in the context of interprovincial or international water concerns, is an important activity of the federal government undertaken by the Inland Waters Directorate (IWD) of Environment Canada. It was determined in 1981 that the potential impact of large expansion in the energy sector on water use and availability required careful assessment. IWD, with the sponsorship of the Department of Energy, Mines and Resources, commissioned Acres International to assist in the development of a computer based water use analysis model (called WUAM). Model development progressed over a 6-yr

period from 1983 to 1988, with the end product being a very comprehensive general analytical tool. Governments at all levels are now placing considerable emphasis on water demand management as a new direction in managing our water resources. The availability of WUAM with its ability to examine water demands and water pricing in considerable detail is very timely.

The complete model represents a river basin as a series of nodes and branches organized in a hierarchical manner. Generally, the node points are selected at stream gauge locations, although definition of intermediate points is possible provided a hydrologic record can be synthesized. The model provides the means for a detailed forecast of future water demands under various economic scenarios. Water demands are determined at each node under five water use categories: domestic, livestock, irrigation, electric energy and industrial. The model can also represent diversions, reservoirs, instream requirements and apportionment constraints at provincial or international boundaries. These demands are compared with available supply, accounting for ground-water supply, on a monthly basis. Tabular and graphical statistics are prepared to assist in interpreting the supply/demand balance.

ASSESSING THE SOCIO-ECONOMIC IMPACTS

OF CLIMATE CHANGE IN MARINE ENVIRONMENTS

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Halifax, Nova Scotia

This presentation reviewed the results of two phases of our project, sponsored by the Canadian Climate Program, to consider the socio-economic implications of future 2 x CO_2 climate scenarios for the marine environment and associated economy of the Atlantic Region. The first phase found that the 3 to 4°C warming indicated by these scenarios would facilitate fishing activities and improve marine transportation, offshore energy, and mineral development in the winter because of reductions in sea ice. A sea level rise of one metre during the next 50 to 100 years would place at risk billions of dollars worth of coastal infrastructure, as well as coastal resources such as beaches and wetlands. Tourism and recreation would likely be enhanced by a more favorable summer climate relative to other parts of eastern and central North America.

The second phase of this project considered the implications of these changes for small coastal communities that are especially dependent on the sectors considered in the first phase. A general conclusion from this phase of the study was that continuing environmental deterioration would tend to exacerbate the costs of climate change, and limit or preclude the potential benefits. With regard to water resources, the prospects of reduced runoff, especially in the southern part of the region, together with sea level rise, could result in greater saltwater intrusion up estuaries and into ground water. It could also threaten freshwater supplies of some coastal communities, and reduce habitat for fish species that use rivers, streams and nearshore waters as spawning and nursery areas. Losses of wetlands would also reduce wildlife habitat.

This project was not a complete integrated regional assessment, because it did not consider other important economic sectors such as forestry and agriculture, not to mention the industrial, service and information sectors. Nevertheless, it did begin to indicate some of the adaptations that climate change will call forth (especially on the part of small coastal communities), at whatever level of society these are initiated.

THE POLICY PERSPECTIVE ON CLIMATE CHANGE AND WATER RESOURCES: INFORMATION NEEDS AND RESOURCE OPTIONS

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Ottawa, Ontario

To review the policy implications of climatic change in any meaningful way is extremely difficult at this stage. The problem is not one of how to speculate intelligently on the policy implications of a specific climate in a specific area, even if that climate is not likely to be characteristic of the area until several decades into the future. The main problem is that our present ability to forecast such regional climates, in response to the greenhouse effect, is extremely limited.

Note that this statement is not an expression of doubt about the reality of the greenhouse effect. Like most atmospheric scientists, I believe the evidence is clear that the global climate will change, and is indeed already changing. Most of our understanding of what is likely to happen, however, rests on Global Circulation Models (GCMs). Because of the assumptions and relationships on which these models are based, I think it is generally agreed that they are more credible in regard to changes in mean sea-level than for changes in the climate of specific land areas; more credible on north-south (latitudinal) changes than east-west (longitudinal) changes; and more credible on probable changes in temperature than to precipitation.

I recognize the immense intellectual effort that is going into the development and improvement of GCMs, and I do not wish to be unduly sceptical. But there are times when I see the projections of future climate - especially regional climates - as a vast amount of speculation and extrapolation based on a very tiny kernel of fact: the Mauna Loa and other measurements of increases in greenhouse gases. This vulnerability has already been dealt with in several papers at this workshop (especially in regard to GCM grid density). The danger of building policy speculation on climatic speculation is obvious.

As well as these difficulties arising from the character of GCMs, there are other problems, of which two deserve particular mention. First, there is the possible catastrophic effect of a rapid rise in global sea level, if all or much of the West Antarctic icesheet were to 'slip' into the Southern Ocean. The GCMs do not provide for this possibility and it too is a matter of speculation; however it is obvious that the policy implications of such a sudden and substantial change in sea level would be enormous.

Second, in regard to gradual changes, the fact that these will be accomplished over a period of decades raises major questions about what impacts are likely to require public policy responses and which ones are likely to be absorbed by market forces, generational differences, and similar mechanisms. Even 'costs' of climatic change estimated in billions or trillions of dollars may be accommodated relatively easily if the period of transition is sufficiently long.

With all these reservations, I looked in turn at four different situations where the policy implications of climatic change seem significant: agriculture in Ontario, the Newfoundland economy, social philosophies of development in the Northwest Territories, and the Walpole Island First Nation (Lake St. Clair). These were chosen not because they seemed either the most important or the most easily defined policy examples, but merely to illustrate the great diversity of policy issues that are likely to arise from climate change.

From these examples, three more general conclusions were drawn:

1) It does not seem possible to search for public policy implications of climatic change on the basis of topic: everything seems to be potentially influenced by a change in climate. Instead, one needs to look at other factors, such as the magnitude of the changes in regard to time, the likelihood that market or similar forces will absorb the changes readily, etc.

2) Integrated studies (e.g., of a provincial economy) are as important as detailed studies of individual components, despite the uncertainties that abound.

3) Climatic change is clearly a field to which social scientists need to be attracted, and in which they must work closely with climatologists, hydrologists and other physical scientists.

REPORT OF WORKING GROUP #1

Chairperson: P. Sly

Rapporteur: M. Clamen

The participants in this working group are listed at the end of this report. This group addressed the six questions that were handed out by the workshop organizers. This report states each question and the pursuant discussions, in sequence.

Q.1 What models would you recommend for use in studying the impacts of climate change on the water resource sector? What models would you not recommend?

Irrespective of the types of model chosen, they should be based on correct science (physics); this applies to empirical models just as much as to deterministic models. GCMs appear to offer some success as a means of estimating changes in temperature as a result of increases in CO_2. However, before more trust can be placed in them, it will be necessary to see if the higher resolution Limited Area Models (LAMs) produce more realistic values based on comparisons with observed data. No one was convinced that the GCMs could replicate 1 x CO_2 climates, let alone predict 2 x CO_2 climates with any degree of certainty. It was recognized that the GCMs were not intended to replicate observed data; it was also recognized that LAMs may not provide sufficient realism either. A hierarchy of models (including hybrid forms) may be required to output predictive values at different scales. A comparison was drawn to the problems of habitat models in fisheries science and the significance of feature scales in model hierarchy (Appendix 1). The GCMs (and LAMs?) do not provide a convincing prediction for precipitation. Evapotranspiration is a key element of model data that appears to be largely missing or very "weak"; much more effort is required to generate required data sets of this variable. Also, we lack good hydrological models; it was felt that we really don't know the current state of water resources. More effort is required to develop reliable watershed models for comparison with the LAMs or higher resolution atmospheric models.

At this time, it was felt that none of the existing GCMs were substantially more reliable than others. Each had special characteristics that could make it useful for different tasks. None of the models were rejected.

Q.2 What types of scenarios (GCMs, paleoclimate, etc.) should be used in climatic change studies?

It was recognized that there are differences between scenarios and forecasts; scenarios are much more generalized and mostly lack confidence limits. It is essential to look at the full range of scenarios that exist. Paleoclimatic data can be useful as a guide to the "averages" and extreme values of past climate, and the areas so affected. The extent to which paleoclimatic data can be used is variable. In most cases, limitations are imposed by not knowing all

the factors that influenced the situation at some past time. Nevertheless, useful implications can be drawn from such data. No single model approach, no set of paleoclimatic data would be sufficient on its own. Scenarios in which model and paleoclimatic data appear to be generally comparable will have the greatest credibility.

Q.3 Are there geographic areas which should be considered as priorities and, if so, why are they priorities?

Yes! Prairie Canada must be a priority because of continuing water shortages and history of climatic extremes. Under climatic warming, it would be essential to prepare this area for new agricultural practices and land use policies, especially since the region may be required to meet dependence by a larger population. The Great Lakes region should also be a priority because of the already high population density of the area, existing high and increasing consumptive use (agriculture and industry), fisheries and recreational demands, and the potential for water transfer out of the region. Northern regions are also a priority because of the likelihood of greatest climatic change taking place in high latitudes (this also includes the need for most basic research, such as proposed by the ICSU - International Geosphere-Biosphere Program...but was not discussed in detail).

Q.4 What are the major (1) technical, (2) scientific, and (3) administrative problems impeding progress in studies of the physical linkages between climate change scenarios and impacts on water resources? What steps should be taken to overcome these obstacles?

1) Climate change scenarios are often too far ahead, we need something in the order of from 1 to 5 years ahead for water resources management. Better observed data are required to characterize evapotranspiration, and to characterize ground-water and soil moisture regimes. Although hydrological processes are reasonably well understood, we don't really understand the environment in which we apply them. Because of the size of Canada, it is particularly difficult to develop adequate climate/hydrology data sets to enable reliable predictive scenarios; long-term data sets at selected sites are absolutely essential and better means of developing spatial relationships are required.

2) Science is made to appear knowing more than it really does. The hydrology of the Boreal Forest Zone and permafrost areas is not well understood, nor are the reflectances of ocean and forest cloud covers. Basic science (deterministic values and process) is lacking for many process studies. There is a need for risk assessment.

3) Departments are not set up to deal with complex interdisciplinary work. There is an urgent need to establish team research across institutional lines, so as to bring together best available expertise. Research funding was raised as an important issue, particularly in relation to internal allocations, and as a concern for grant submissions where interdisciplinary proposals often "fall between stools."

Q.5 What scale of phenomena should be considered in studies of the impacts of climatic change on water resources?

All! Recognize that a multiplicity of scales is useful. From a hydrological perspective, small-scale models are generally most appropriate for impact studies. For process analyses, medium and large-scale models are required. Probabilistic models are required to address such things as patchiness of phenomena and hurricane periodicities.

Q.6 Given Canada's scarce financial resources, what water/climate-related goals should be given highest priority? Note: This question was revised by the working group.

Models--scale to be appropriate to problems, improve to be more realistic, try to improve GCM/LAM resolution.

Scenarios--cover a broader range and greater variability of climate, and develop short-term projections for 1-5 years ahead.

Process understanding--ocean/atmosphere link (including associations between Canadian climatic conditions and El Niño type events), cloud albedo, evapotranspiration, snowmelt, vegetation feedback, and processes in high latitude environments. Assess, carefully, just how far deterministic analyses vs. probabilistic analyses can provide useful data. Seek better links between deterministic and other predictive climate models, with hydrology and paleoclimate models/data.

Monitoring--radiative measurements, long-term hydrological monitoring at key sites; quality and quantity of data need to be improved.

Administration--take an integrated, team approach to specific topics/regions; focus research resources and don't spread them around; link specialists in government, industry, and universities, and bring together water quality/quantity, atmospheric, and socio-economic specialists.

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APPENDIX

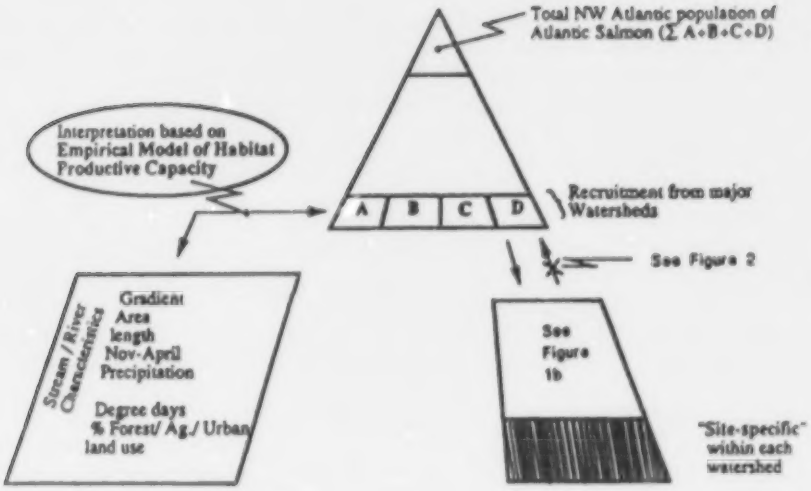
Hierarchical Scales

The following material illustrates scalar differences in data derived at various levels within an aquatic habitat classification system. It is based on an example of Atlantic salmon river habitat. The total northwest Atlantic salmon population is assumed to be composed of stocks A, B, C, D, ..., each of which spawns in a different watershed. Productive capacity is used to describe the yield of smolts. In Figure 1a, some form of empirical model is used to estimate the productive capacity of aquatic habitat; examples of possible variables illustrate the types of information that may be required. These data (type "C") are characterized as large scale and low resolution; they are relatively stable and many are naturally integrative.

Within each watershed, each river or stream can be further divided into numerous smaller site-specific units. Based on a detailed knowledge of habitat requirements such as used to establish a habitat suitability index, the river and stream units can be functionally grouped as spawning, nursery, juvenile, and other forms, and summed to produce total habitat area or volume. Site-specific information needs are characterized by type "C" data, and the lack of inherent stability in these data is illustrated in the plots of a generic variable (Fig. 1b).

At first glance, it may seem possible to refine estimates of habitat productivity based on type "C" data, by carefully collecting large quantities of site-specific type "C" data and adding them together for each watershed. Estimates of habitat areas or volumes based on the summation of site-specific data give the potential productive capacity of habitat, but rarely is this equal to its actual productive capacity. This is because many of the functions that control habitat use and availability are probabilistic in nature; although the effects of such functions may be to increase species diversity they also decrease the productivity of individual species. For example, good spawning habitat may be limited by the effects of winter ice after egg deposition, or changes in flow regime may result in juvenile crowding within summer pool habitats. These constraints are extremely difficult to quantify, but, collectively, they create the boundaries of critical habitat. The actual productive capacity of habitat is most closely related to critical habitat (assuming that stocks are not otherwise limited by excessive harvest).

Figure 2 illustrates the difference between data reduction and synthesis, as applied to low and high resolution data (equivalent to large and small scale data). Reduction passes downwards through the scalar hierarchy and through levels of natural integration to develop cause and effect relationships and to quantify them in a deterministic fashion. Synthesis (which moves in the opposite direction) requires the use of some form of probability function to link between different levels of data resolution. Where such probabilities cannot be measured, synthesis may be undertaken through statistical analysis. This involves the construction of simulated probabilities by means of purely mathematical formulation. Depending upon the direction in which analysis is progressing, the same structural point



TYPE "C" DATA (Examples)

(Relatively stable at the entire watershed level and at annual perodicities)

LARGE SCALE LOW - RESOLUTION

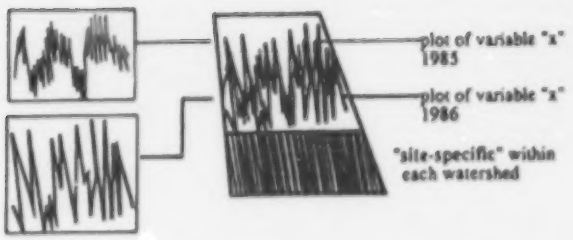
D=∑ a+b+c+c+d.....)

TYPE "c" DATA

(site -specific and highly variable data)

SMALL SCALE HIGH - RESOLUTION

Figure 1a



TYPE "c" Data *

Water temperature
Flow velocity
Depth
Substrate type
WQ nutrients
WQ toxics
Interspecies/ community structure

SITE SPECIFIC CHARACTERIZATION OF POTENTIAL PRODUCTIVE CAPACITY OF HABITAT

* each as a regime differing in space and time across a watershed daily, seasonally, yearly, etc.

Figure 1b

between different levels of scale may be seen as one of integration or probability. Stated simply, it is easier to derive reliable interpretations based on a top-down (reductionist) analysis of data; it is harder to do the reverse (which also requires large quantities of data); it is unlikely that fish yield predictions based only on the summation of detailed site-specific data will substantially improve predictions based on the naturally integrated data typical of the upper levels of scalar hierarchy. However, it is possible to "hybridize" data from different levels of hierarchy. For example, type "C" data can be collected from a number of type locations and then expanded, based on the amount of such habitat in the total watershed (as indicated by type "C" data). The extent to which this approach can improve estimates of actual productive capacity remains uncertain. Almost certainly, the approach must be watershed-specific as well as species-specific.

Type "C" data are an essential tool for site-specific habitat management, including the identification of critical habitat and the expansion of its time-space volume (enhancement of productive capacity). Type "C" data are essential for regional planning, and the control of harvesting. Both sets of information are complementary but, also, they illustrate the incompatibilities inherent in non-hierarchical habitat classification systems.

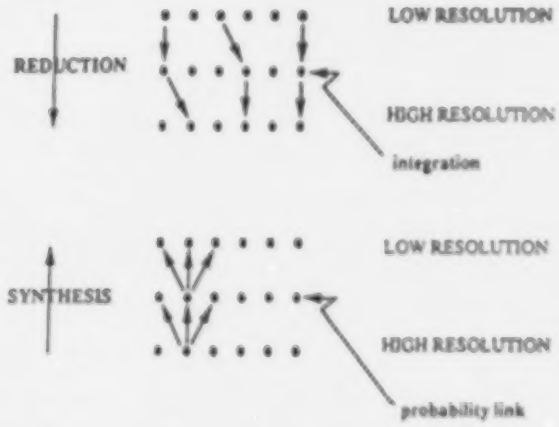


Figure 2

REPORT OF WORKING GROUP #2

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Rapporteur: E. Wheaton

Q.1 What models would you recommend (and not recommend) for use in assisting the physical impacts of climate change on water resources?

Our group interpreted this question to mean "hydrologic" models, assuming the climate change scenarios as given. It was agreed that most hydrologists had their favorite regional model to estimate runoff given a specific change in temperature and precipitation. One recommendation was the Thornthwaite-Mather water balance model, which is widely applicable since it requires only data on temperature to estimate potential evapotranspiration for a long-time series.

With regard to the climate change models (GCMs), the group did not wish to recommend any specific model since none gave good values of regional precipitation.

Q.2 Given Canada's scarce resources, what goals within the climate research program should be given highest priority?

The group agreed that the basic need of the GCM modellers is for computing power and more people power in order to provide the water researchers with regional output on a scale that they can use (LAMs or limited area models). One suggestion was collaborative research with the U.S. in a case study, such as the Great Lakes basin.

Q.3 What adjustments should GCM modellers make to their outputs to make them more useful in impact studies?

The consensus here was that it would be desirable to have the output reflect earth surfaces more realistically; e.g., lakes, mountains. It was stated that regional precipitation was the output most needed, and that hydrologists could then use their own models to estimate runoff.

Q.4 What are the major technical, scientific, and administrative problems impeding progress in studies of the physical linkages between climate change scenarios and impacts on water resources? What steps should be taken to overcome these obstacles?

The group felt that a major problem is that physical processes are still not adequately understood, especially evapotranspiration and soil moisture. There is also a problem of measurement of precipitation (to adequately reflect areal rather than point precipitation). The consensus was that more regional studies (e.g., Prairie, Great Lakes basin) are the top priority.

The group felt that the following issues should be dealt with on a priority basis by the Canadian Climate Program:

- Case study of Great Lakes basin and climate changes
- Improved communication with public
- Regional orientation of studies (e.g., Prairies)
- Research in evaporation and soil moisture
- Development of private sector expertise (e.g., Ontario Hydro)
- Public awareness of climate change issues
- Improved climate change models
- Accurate data for verification of models
- Water related goals stated in Canadian Climate Program

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REPORT OF WORKING GROUP #3

Chairperson: L. Maltby

Rapporteur: L. Grima

The participants began by addressing the need to identify areas, both geographic and sectorial (i.e., agriculture, utilities, etc.) that should be given priority in socio-economic impact studies. First, criteria should be developed, and it was suggested that an important factor should be the significance of the relationship between water supply and the economy for specific regions and activities. Examples given include coastal regions, the Prairies, the Great Lakes, agriculture, transportation, and hydroelectric production. Second, public values and changes in public values are implicit considerations in the discourse on issues such as climate change and its role in a larger context, such as sustainable development. Third, there is a need to know the right questions to ask and the appropriate information to collect in order to affect policy-making in, say, 1995. Finally, the research response now (i.e., 1989) to the possibility of climate change must be assessed in terms of its relevance and effectiveness.

The limitations and strengths of the socio-economic effort in climate change studies was the next topic of discussion. It was suggested that the major limitation facing social scientists is the need to fit socio-economic research and policy analysis into a biophysical "agenda" and mode of intellectual discourse. In response, researchers must clearly identify the points of contact between the two areas of discipline. The social science emphasis should be on the adaptation of people in a constantly changing society. The concepts of social and biophysical resilience and an integrative research approach are important considerations. Historical analogues of societal adaptation should be used in socio-economic impact studies.

The next issue addressed was the distinction between social and economic effects in climate change impact research. For example, there are both social (behavioral) and economic responses that need to be identified in order to slow down the build-up of carbon dioxide in the atmosphere. Furthermore, there are both social and economic options in terms of dealing with the inevitable effects of carbon dioxide build-up and climate change. A key research effort should be to improve interdisciplinary and inter-institutional communication through special events such as the current workshop. Response strategy planning and decision-making should be inter-jurisdictional and international in nature. In terms of preferred research approaches and methodologies, it was suggested that all those currently in use for social and economic impact assessments are legitimate and should continue to be applied, given the developmental state of climate change research.

The discussion concluded with the following recommendations: First, interdisciplinary research projects and ongoing programs on the impacts and responses to climate change should be developed immediately and should

involve government organizations, universities, the private sector, and non-government organizations. Second, the process of developing and applying priorities for socio-economic studies in climate change research, including funding mechanisms, should be revieved jointly by representatives of the general research community and the Socio-Economic Impacts Committee of the Canadian Climate Program. Finally, it was agreed that addressing the issue of a research agenda, priorities, and key questions is in itself an appropriate project and should be supported on a regular basis by netvorking among experts and information synthesis, analysis and dissemination.

The discussions in the above group were based on the following questions:

1. What are the most significant limitations and strengths in the socio-economic impact studies to date?

2. Hov can social impacts be assessed in a form that will allov them to be considered in the same context as economic impacts?

3. What role do input/output models have in the assessment of the impacts associated with climatic change?

4. What geographic areas and what vater-related industries (e.g., agriculture, utilities, etc.) should be given priority in socio-economic impact studies? (State the reasons for your priorities.)

5. What goals should be set for future socio-economic impact studies of climate change and water resources? (List in order of priority.)

6. Could risk assessment methodologies be effectively applied in climate change/vater resource impact studies? If so, hov should ve proceed with such studies?

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REPORT OF WORKING GROUP #4

Chairperson: R. Effer

Rapporteur: P. Stokoe

The discussion began with an emphasis on the need to identify clearly the problem(s) to be addressed by socio-economic studies. The current situation in terms of how society responds/adapts to changes in the water cycle and how water is managed must be studied and assessed. Research should focus on the flexibility of water resource systems, using vulnerability indicators, and on the rationale used for the allocation of water. Test cases are needed to illustrate how factors such as the political infrastructure and social expectations influence flexibility and elasticity of water basin management. Addressing the issue of problem-solving in the face of uncertainty should begin at the design stage in water resource management. The general public must understand how water is managed. It is important that technical solutions should support social choices. For the example of overbuilding structures, the acceptable level of reliability of water systems should be re-evaluated in light of new value systems that are emerging in society.

The public requires a better understanding of the science of climatology and in particular, the difference between climate variability and climate change (trends). Climate change is likely to include a change in variability. Also requiring clarification is whether or not a clear signal of climate change has been detected. The direct involvement of scientists in educating the public needs to be addressed. Among the scientists themselves, better efforts are required in bridging the gap between the social and biophysical disciplines. Research on the hydrologic impacts of climate change should produce more information on changes in the incidence of extreme events. This would assist social scientists studying the vulnerability of individuals, communities and society in general.

Discussion of the obstacles encountered in socio-economic impact studies began with ignorance of information needs of water users and lack of identification of vulnerable water users by basin. The dollar value of access to water requires attention. Biophysical indicators of climate change that have monetary values for industries and other water users, and the associated data collection, need to be identified. Clues to the dollar value of water, both economically and socially, may be found in the way society ranks the uses of water in terms of it being a scarce resource. Whether monetary arguments could be the driving force behind the validity of using discount rates in these types of economic analyses still requires resolution.

There are no data available that indicate the minimum water supplies needed to maintain various ecological processes. Data gaps remain with regard to consumptive uses of water, such as irrigation. The bridge between technical knowledge, as noted above, and decision making should be strengthened. This research approach requires enhanced funding, a new literature base, and interdisciplinary contact between industry and

government and among the various governments. The obvious research option once potential impacts are identified is to move from fragmented assessment to analysis of whole systems.

Part of the problem of linking the results of socio-economic studies to government policy making is the often unclear criteria used in choosing required research. Every local impact may not need a policy solution, even though the public sector does have some responsibility to the private sector. Integrated regional assessment can be applied now by building from small to large solutions. By 2010, when it is believed uncertainties about climate change will be reduced, its socio-economic implications should be integrated into fiscal policy.

The decision-making process at all levels should be examined by tracking the development of solutions to problems through social systems. This could lead to the identification of areas of low uncertainty and decision nodes at which there is likely to be a desirable response to pressure. One could learn if society actually functions on the basis of individual sectors or types of livelihood, as socio-economic research so often presumes. Information on societal responses to uncertainty is needed. For the general public to cope with and understand uncertainty depends largely on the dissemination of appropriate information by journalists and other media types that are properly educated on the subject. Even when faced with a range of possible impacts rather than definite answers, people are capable of decision-making.

A rational mechanism for politicians to anticipate crises and to develop long-term policies, given the uncertainty of climate change impacts, will be difficult to achieve. The basic trade-off is between the short-term political horizon and intergenerational equity. Progress in the former may require glamorizing the climate change issue, which is already occurring to a certain extent. On the other hand, consensus for long-term solutions could be achieved through the environment/economy roundtables with the focus on sustainable development.

The evolution of water resource management in response to the likelihood of climate change will require information beyond the usual probability types. For example, information on changing societal values may force water managers to rationalize small-scale projects in terms of integrating local autonomy with regional management while maintaining some of the flexibility provided by the usual mega-scale solution. The uncertainty of climate change calls for new forms of water planning that recognize that the changing value systems of people, particularly those of water users, have significant policy implications. Therefore, social scientists must be involved in water management and planning discussions on climate change.

The most vulnerable aspects of water management include large inflexible municipal infrastructures (i.e. for drinking water). Special attention should be given to large physical structures such as dams and reservoirs. The more vulnerable economic sectors are agriculture, fisheries, navigation, and tourism. Therefore, a goal for future socio-economic impacts research should be the typing and rating of system vulnerabilities, that is, as social, economic, engineering, or ecological. The identification and assessment of climate change impacts, both as benefits

(opportunities) and costs, should be integrated at a regional scale. Finally, historical analogue research that links the human response to climatic variability should be applied more vigorously to the issue of climate change and forecasting its potential socio-economic impacts.

The discussions in this group were based on the following questions:

1) What are the major obstacles in doing socio-economic impact studies and what changes/developments are needed to overcome each of them?

2) What aspects of water resource management are most vulnerable to climate change impacts? (List from most significant to least significant.)

3) What steps should be taken to link the results of socio-economic studies to government policy at the present time? In 20 years from now?

4) What types of information are needed in order to assess the way in which water resource management will need to evolve with changed climate?

5) How can the local socio-economic impacts of climate change be accurately related to provincial and national impacts?

6) What goals should be set for future socio-economic impact studies of climate change and water resources? (List in order of priority.)

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Alan Stanley
Peter Stokoe (Rapporteur)

AGENDA

Workshop on the Impacts of Climatic Change on the Water Resources Sector

National Hydrology Research Centre
11 Innovation Blvd.
Saskatoon, Sask.

May 17, 18, 1989

Objectives of the Workshop

1. To develop recommendations for the Canadian Climate Program Planning Board regarding priorities for research dealing with the socio-economic impacts of climate-induced variations and changes in water supply and demand patterns.

2. To facilitate an exchange of information regarding Canadian studies of the impacts of climatic change on water resources.

May 17

Canadian Climate Program Activities

08:30 - 08:50 Introductory Remarks

08:50 - 09:20 Structure and Objectives of the Canadian Climate Program (Mrs. N. Cutler)

09:20 - 10:00 Status of Global Circulation Models and their outputs (Dr. N. MacFarlane)

10:00 - 10:20 Coffee

National and Regional Water Resource Management Issues

10:20 - 11:00 National Water Resource Issues (Dr. A. Stanley)

11:00 - 11:30 Uncertainties and Issues in Water Management in the Great Lakes Basin (Mr. D. Cuthbert)

11:30 - 12:00 Uncertainties and Issues for Water Management in Western Canada (Mr. D. Bjonback)

12:00 - 13:00 Lunch

Status of Methodologies for Interpreting Hydrological Impacts of Climate Change

13:00 - 13:30 Overview of Methods Used in Assessing the Impacts of Climate Change on Water Resources (Dr. S. Cohen)

13:30 - 14:00 Possible Hydrological Impacts of Climate Change in Western and Northern Canada: Methods and Findings (Dr. G. McBean)

14:00 - 14:30 Possible Hydrological Impacts of Climate Change in Eastern Canada (including the Great Lakes Basin): Methods and Findings (Mr. A. Saulesleja)

14:30 - 14:45 Climate Change and Water Quality (Mr. P. Brooksbank)

14:45 - 15:00 Coffee

Status of Methodologies for Addressing the Social and Economic Impacts of Climate-Induced Changes in the Water Supply and Demand Patterns

15:00 - 15:30 Overview of Methods Used in Assessing the Socio-Economic Impacts of Climate Change (Dr. A.P. Grima)

15:30 - 16:00 Translating Hydrological Data and Predictions into Socio-Economic Impacts: Methods and Models (Mr. B. McClennan)

16:00 - 16:30 Assessing the Socio-Economic Impacts of Climate Change in Marine Environments (Dr. P. Stokoe)

16:30 - 17:00 The Policy Perspective on Climate Change and Water Resources: Information Needs and Response Options (Dr. C.I. Jackson)

May 18

08:30 - 08:40 Plenary Session: Introduction to Working Groups

08:40 - 10:30 Working Groups:
Group A - Assessing the Hydrological Impacts of Climate Change
Group B - Assessing the Socio-Economic Impacts of Climatic Change on Water Resources

10:30 - 10:45 Coffee

10:45 - 11:45 Plenary Session with Workshop Reports and Discussion

11:45 - 12:00 Workshop Summary

12:00 - 12:10 Closing Remarks

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May 17-18, 1989
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